Preparing for the Future of Systems Engineering

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Every so often, people need to review past efforts, examine progress, and reassess future activities. After more than 40 years of practicing systems engineering within the Department of Defense, it is time we do just that. We must review past policy, guidance, case studies, and best practices; examine current work in engineering standards and processes; and reassess training and growth of the senior engineering workforce. This will require more than a coordinated update of the systems engineering chapter in the *Defense Acquisition Guide*. And we must ask how DoD can improve the current application of systems engineering by its organic and contracted workforce, and how can DoD collectively influence the application of systems engineering in the future?

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Historical Perspective

In 1994, William Perry, then secretary of defense, issued a policy memorandum to eliminate all non-interface military standards and specifications. MIL-STD-499B, entitled *Engineering Management*, was the systems engineering standard originally released in 1969 and updated in 1974, and it was under review in 1994 when it was eliminated by Perry's memo. After several major catastrophic weapons system malfunctions, the military services began a concerted effort to reassert their own policies. For example, in the late 1990s, the Air Force established the Operational Suitability, Safety, and Effectiveness Program, which was an effort to improve the application of a subset of their more critical systems engineering processes. In a parallel effort, the Navy developed the *NAVAIR Systems Engineering Guide*.

Still faced with unending cost overruns and performance failures, the Office of the Secretary of Defense embarked on a series of efforts to revitalize systems engineering over the last few years. One of the most visible efforts taken was the 2004 Office of the Under Secretary of Defense for Acquisition, Technology and Logistics policy requiring all programs to develop a systems engineering plan for milestone decision authority approval at all milestone reviews. This action definitely got program management attention on OSD's new emphasis on improved planning and systems engineering execution. The next revision to DoD Instruction 5000.02 is expected to continue to embrace the use of systems engi-

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neering plans. OSD's systems engineering revitalization has also filtered down to the military services. Efforts continue to reassess systems engineering policies and instructions, develop guides and handbooks, engage in graduate and short-term systems engineering degrees and certificates, and establish civilian and military job series.

OSD also sponsored a series of National Defense Industrial Association studies that uncovered "Top 5" issues as well as quantified the value of systems engineering. As validation across government and industry, the original 2006 report identified a lack of systems engineering awareness, adequate systems engineering resources available to major programs, insufficient tools and methods to effectively execute systems engineering, inconsistent application of requirements definition and management, and poor initial programming.

Increased Complexity

Architecture has been one area of early systems engineering that has generated a consistently increasing amount of attention. Within DoD, this dates back to interoperability problems uncovered by joint warfighting in the first Gulf War. The C4ISR [*Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance*] Architecture Framework was released and re-released in the mid-1990s to address the system design of interoperable, networked systems. It would become the DoD Architecture Framework in 2004 and codified in Joint Capability Integration and Documentation Systems, Acquisition Management Systems (DoD 5000), and numerous Service policies and instructions.

Increased complexity of the weapons systems that DoD acquires will continue, with no end in sight. With greater program and system interdependencies, larger software and networked weapons systems will flourish. Meeting performance, cost, and schedule goals continues to challenge many DoD programs. U.S. Government Accountability Office reports, such as their *Assessment of Selected Major Weapon Programs* (GAO-06-391), found several consistent factors that contributed to DoD's ability to handle such complexity. The major systems engineering contributors included requirements, reliability, test planning, and software. GAO reported that current efforts have "not eliminated cost and schedule problems for major weapons development programs." If the challenges of current systems engineering cannot be resolved, that may only indicate greater challenges are in store for us in acquiring more integrated, network-centric weapons systems in the future.

Current Perspective and Growth of the Discipline

In January 2004, the International Council on Systems Engineering (INCOSE) brought together experts to perform an in-depth study on the future state of systems engineering. The council published its report in October 2007 with the Systems Engineering Technical Vision (found at <www.incose.org>), stating:

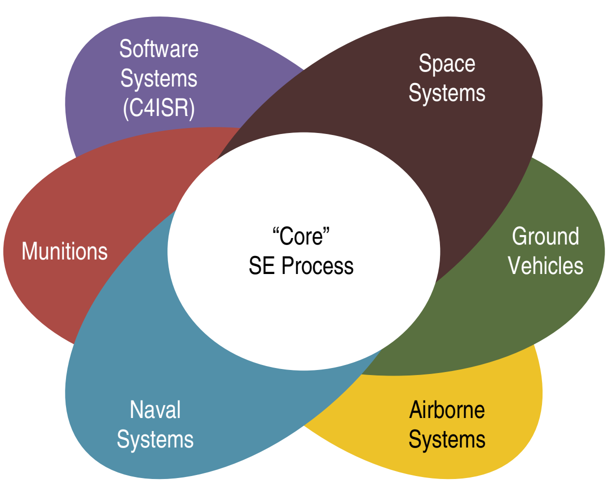
> *Systems engineering will become an established international "inter-disciplinary connector" or a "meta-discipline."… With the maturation of the global practice of systems engineering, as well as the stronger understanding of how to handle complex systems, systems engineering will advance into addressing the social, economic, environmental, and planning issues of the time.*

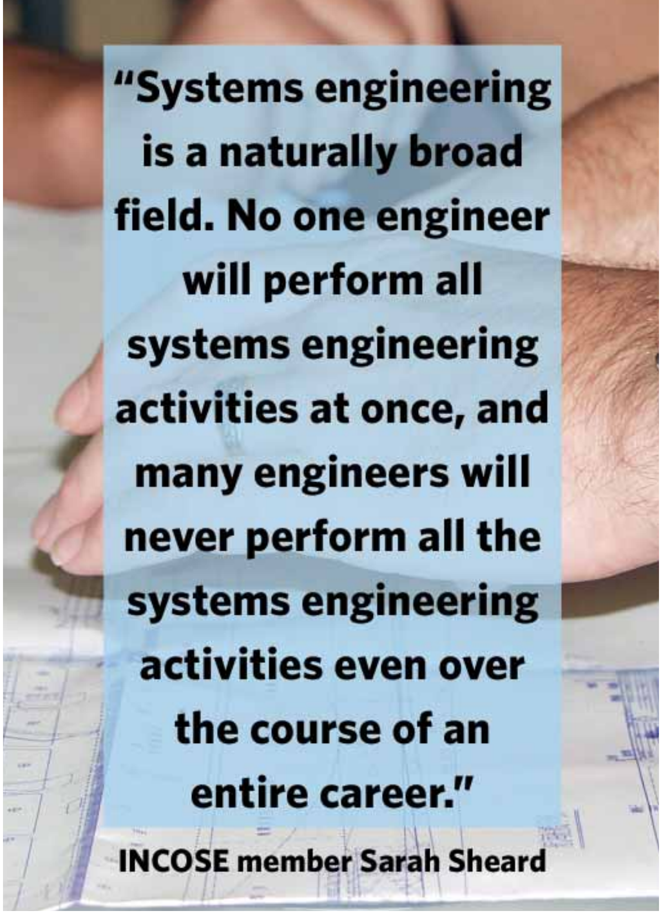
This position for the growth and maturation of the discipline aligns with a number of National Academy of Engineering (<www.nae.edu>) and industry professional society studies and academic engineering periodicals. It is understandable during this time of systems engineering growth that when a group of experienced systems engineers gathers, many different opinions emerge. This is because most senior systems engineers have had very divergent, yet relevant, work experiences within their domain of experience. These engineers executed tailored versions of a global core systems engineering process, as shown in Figure 1. The visions of what systems engineering embodies, etched in these systems engineers' minds, is the basis of what they each bring to the table. For example, some engineers in the space community firmly believe that space systems engineering is a different discipline of study. Perhaps this belief is the result of focusing on the space domain's unique environment (thermal and radiation), technical challenges (launch, power consumption, control) or areas of emphasis (parts ultra-reliability) while overlooking systems engineering commonality. Moreover, many believe a person is a competent systems engineer if the person writes plans, specifications, and interface control documents, and uses the vernacular of the systems engineering profession. But if you understand art, does it make you an artist? No. There is clearly an experiential component to engineering and systems engineering.

Future Harmonization of Terms

At the 1996 INCOSE Symposium, member Sarah Sheard remarked, "Systems engineering is a naturally broad field. No

Figure 1: **Core Systems Engineering Process**





one engineer will perform all systems engineering activities at once, and many engineers will never perform all the systems engineering activities even over the course of an entire career." Priorities vary from project to project and resources for accomplishing systems engineering tasks vary as well. In order to contain this divergence, a universal agreement on the global systems engineering process, the names given to the process, and the definition of the activities and products produced by each process, is long overdue.

However, there still is not a single standard for systems engineering process and terms. Although harmonization has begun between the various standard committees, the three main applicable standards are:

- ISO 15288, *Systems Engineering-System Life Cycle Processes*
- Institute of Electrical and Electronics Engineers (IEEE) 1220, *Standard for Application and Management of the Systems Engineering Process*
- Electronic Industries Alliance (EIA) 632, *Processes for Engineering a System.*

The schedule for harmonization efforts, dictated by the International Standards Organization (ISO) country agreements and voting/vetting process, is a lengthy and political one. The IEEE 1220 Standard Committee is working closely with the released 2008 update to ISO 15288 and is planning to publish IEEE 15288 soon. The EIA 632 Standard Committee is aware of the ISO/IEEE 15288 harmonization efforts and is currently in the process of updating their standard. Each of these standard committees believes their approach is correct. From a top level of abstraction, the major differences between the standards are the specific nomenclature and definitions. Adding more confusion to this mix is the fact that there are two systems engineering guidebooks and no firm resolution on which is *the* authority on systems engineering: DoD's *Defense Acquisition Guidebook* and the *INCOSE Handbook*. The *Defense Acquisition Guidebook* supports the Defense Acquisition Workforce Improvement Act acquisition professional certification levels taught by the Defense Acquisition University. The *INCOSE Handbook* is a community-generated systems engineering process description, aligned with ISO 15288, and it is used to certify systems engineers.

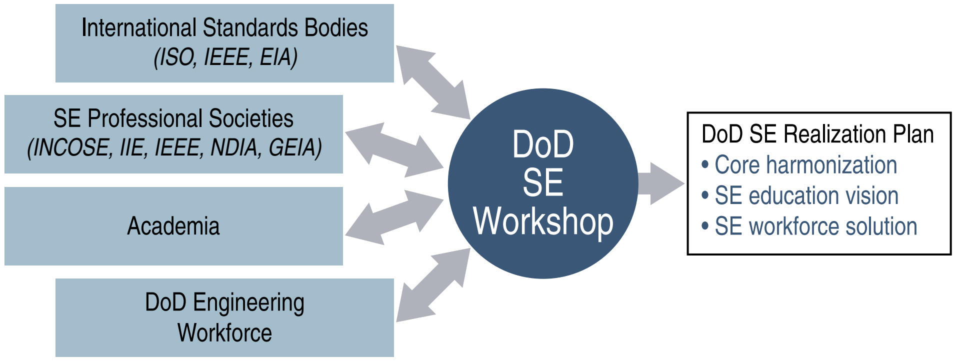
In order to expedite the harmonization efforts, each of the standard committees must accept a single global systems engineering nomenclature and definition. Attainment of standardization is an essential and foundational building block upon which systems engineering education must rely. The formal release of ISO 15288-2008 should signal all other standard committees to update their standards and to show consistency. Tailoring guidance to apply these newly agreed-upon standards is overdue and should enable program teams of the future to better apply systems engineering. Assessment guidance to measure application of scalable processes will go a long way toward ensuring systems engineering consistency.

Future of Systems Engineers

One of the most critical issues identified across the international community is that there are not enough qualified systems engineers. A recent job search on Monster.com and Careerbuilder.com indicated more than 2,000 systems engineers were needed across the country. This issue is not likely to wane in the future. In a June 2008 *New York Times* article, "Top Engineers Shun Military; Concern Grows," Philip Taubman reported on the brain drain of scientists and engineers within the defense industry. While he did not provide numbers of lost engineers, Taubman suggested that the discipline of systems engineering was the most affected. He wrote, "The central problem is a breakdown in the most basic element of any big military project: accurately assessing at the outset whether the technological goals are attainable and affordable, then managing the engineering to ensure that hardware and software are properly designed, tested and integrated. The technical term for the discipline is systems engineering. Without it, projects can turn into chaotic, costly failures."

Thus far, organizations have focused on the amount of time it takes to mature systems engineers from existing disciplined engineers already in the workforce. Recent updates by the academic community in graduate education have not captured the momentum needed to make an impact for the future. While positive educational benefits to individual students exist today, it is impossible to capture the direct impact on programs. An innovative approach to identify

Figure 2: **Plan for Future Systems Engineering**



and target talent early, defined by academia and industrial/government organizations, is long overdue. This approach should also include a more aggressive area of concentration at the graduate and undergraduate levels, as well as continuing systems engineering education for the workforce.

Early Identification of Talent

Through standardized testing, K-12 students could be identified as having natural systems thinking, logical abstraction, analytical, and engineering characteristics. (Note: Natural systems thinking involves a child's showing an understanding of systems without being taught how.) In some well-referenced studies, such as the 2006 MIT dissertation entitled *Enabling Systems Thinking to Accelerate the Development of Senior Systems Engineers* by Heidi Davidz, other characteristics have been proposed to be equally important:

- Broad or out-of-the-box thinking
- Curiosity
- Strong communication skills
- Open-mindedness
- Strong interpersonal skills
- Tolerance for uncertainty
- Questioning
- Multitasking skills.

Many connect these traits to personality type. A development program for those students to expand these characteristics could be beneficial. There are many scattered development programs across the United States that create curricula to apply scientific, technical, engineering, and mathematical lessons to the K-12 environments. An integration of the products generated from these programs would benefit all of the independent organizations in that those products could be made available for all of the programs. Identified students, strong in systems thinking, should excel in these application areas. Further encouragement can guide these students into technical areas of interest.

Future of Systems Engineering Education

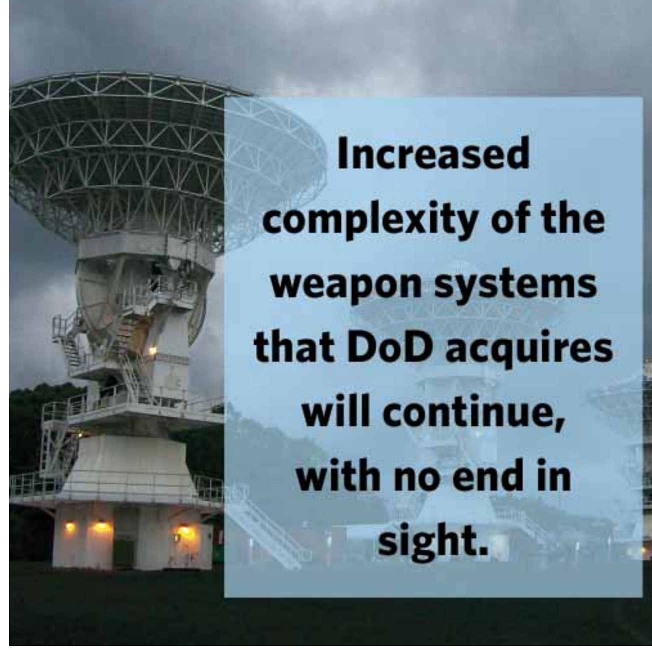
In undergraduate education, and especially graduate school, every student planning to work in industry or government (not just systems engineers, but also accountants, contracting officers, program managers, and marketing managers) needs to take a course in introductory systems thinking. The students should recognize that their office fits into the enterprise, that their component fits into a system, and that their system must be interoperable across a system of systems. Suboptimization and contextual relationships must be evaluated. This type of course complements any major course of focused, disciplined study.

In colleges of science and engineering, systems engineering concepts and fundamentals should form the curriculum for lower-level courses. In addition, a new systems engineering management field of study could emphasize the integration of technical, cost/schedule, communication, and risk management issues. Finally, engineering schools should re-examine how to best attract and educate young students. As systems become more complex and adaptive, the typical engineering abilities of analysis (breaking down) need to be further enhanced with more synthesis (putting together). The knowledge, skills, and abilities to think about the system-level characteristics of the aggregation of complex components, including the human user, is a skill for all disciplined engineers. If there are not enough qualified engineers coming out of the graduate systems engineering education pipeline, innovative ways must be found to increase the input numbers of available engineers to enter the pipeline, subsequently affecting the output numbers. For example, identify systems thinking skills in elementary school students or provide more hands-on engineering laboratory or orientation coursework early in a freshman engineering program to encourage undecided students to obtain a (systems) engineering degree.

Continuing professional education will need to further embrace distance learning to better reach the entire DoD acquisition workforce. Development programs created to earmark high-potential employees should steer them to advanced graduate education in systems engineering, industrial engineering, or systems engineering management. Core competencies in systems engineering will help, as well as a method of establishing performance accountability. On-the-job training programs must also contribute to those systems engineering development programs, including the life and work experiences that are critical for success. The right integrated approach, defined by an experienced academic council and guided by a professional society, will be critical for success, and a roadmap needs to be developed to communicate the integrated aspects to meet this challenge.

Call to Action

Prior to acquisition reform of the early 1990s, government senior engineers incorporated best practices and lessons learned into their military specifications and standards. For example, MIL-STD-499B was to be the premier guide for



applying systems engineering to DoD acquisition. With the elimination of military specifications and standards during acquisition reform, DoD began to rely only on best commercial practices. This included best commercial practices for systems engineering.

Once again, it is the time for government systems engineers to work together to shape the future. As depicted in Figure 2, a DoD realization plan for future systems engineering is a realistic near-term goal. This plan needs championing by senior engineering evangelists—highly respected, charismatic leaders—and recognized senior engineers committed to this critical task. A DoD Systems Engineering Workshop to address those issues could begin to map the way. The effort needs to start now, with an aggressive approach to harmonizing the systems engineering processes within the *Defense Acquisition Guide* based on the globally accepted definition of systems engineering in ISO/IEEE 15288. That is a challenge to the engineering community concerned about the evolution and improvements needed for future DoD application of systems engineering. If systems engineering is to successfully address weapons systems performance in an environment of growing complexity, those issues need to be addressed.

Our starting point must be a plan to assure we have the systems engineering resources available to meet this growing demand. Developing systems engineers is, in part, a function of education, which must rely upon commonly accepted standard practices that are conveyed to the student. Without those standard practices and processes, systems engineers cannot be reliably grown. The time to address these root cause problems is far overdue.

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